PALEOMAGNETIC DETERMINATIONS OF GREEN RIVER OIL SHALES OF THE PICEANCE CREEK BASIN, COLORADO

A Thesis submitted in Partial Fulfillment of the Requirements for the Degree Bachelor of Science in the College of Mathematics and Physical Sciences of the Ohio State University.

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Abstract

A paleomagnetic investigation of the kerogen rich "oil shale" of Piceance Creek Basin (Eocene) indicates a virtual geomagnetic pole at 50.73° north latitude, 150.93° east longitude with a precision parameter (k) equal to 5.01 and a cone of confidence (alpha 95) equal to 11.75. All samples studied indicate a negative inclination and scattered declinations. This result was determined from measurement of thirty-seven cores derived from one hand sample. The majority of samples were exposed to 400 oersted alternating field demagnetization. The result lies considerably south from the mean of previous determinations of the Eocene epoch (Tertiary) pole for North America.

Acknowledgments

My appreciation is extended to Dr. Hallan C. Noltimier for his considerable assistance in introducing me to paleomagnetism, and the paleomagnetic techniques employed in this study. Further, for his continued efforts in obtaining an oriented sample, for allowing me the opportunity to proceed with this project, and his assistance in data interpretation.

I wish to thank the Department of Geology and Mineralogy for the use of all laboratory equipment and computer utilization.

Gratitude is also extended to Martin A. Kopacz, whose assistance and guidance throughout this project contributed to its successful completion.

Forward

One hand sample block of oil shale, originating from the Piceance Creek Basin, Garfield County, Colorado, had been submitted to the Ohio State University for the purpose of paleomagnetic investigation. At the request of Dr. H. C. Noltimier, the sample was provided by Mr. Donald B. Tait, Area Geologist for the Atlantic Richfield Company.

The purpose of this investigation was to:

(1) determine the magnetic properties and the possibility of the sample having a stable magnetic moment.

(2) determine the declination and inclination of the stable magnetization of the sample.

(3) locate the position of the virtual geomagnetic pole as indicated by such measurements.

(4) compare these data against other pole positions which have been previously reported.

(5) speculate on the polarity events which have been identified in the Eocene epoch and possibly locate this unit in the earth's history of geomagnetic polarity.

This investigation is one of very few attempts to study the paleomagnetism of rocks of this nature, and it is hoped that the information contained herein can be utilized or correlated with future results.

Location

Due to insufficient information, the exact locality from which the submitted sample originated can only be speculated. However, it is known that the sample was derived from the Piceance Creek Basin. In an attempt to trace the locality, a road guide describing the geology of Colorado was used. According to the description of the guide, the apparent accessability of the outcrop, and the examination of topographic quadrangles, the most probable location was, apparently, found. The axis of the Piceance Creek Basin, containing the richest and thickest sequences of exposed oil shales, extends through the head of the Parachute Creek Valley (Grand Valley 7.5 minute quadrangle). The location is in Garfield County (T 6 S, R 95 W, Section 28, 29, or 33), approximately 16.5 miles southwest of Rifle Colorado. Latitude and longitude were assigned for the purpose of the experiment.

Depositional Environment and Mineralogy

The sedimentary characteristics of the Green River Formation are quite variable at each outcrop. However, the shales of the Piceance Creek Basin are recognized as having the highest petroleum potential. It has been reported by Dr. Ronald Surdam that numerous loop structures occur within those oil shales of high oil yield. The possible origins of these loop structures are many. They could result from soft sediment deformation, mudcracks, blister mats, salt growth, shearing, or isoclinal folding and faulting. It is believed that this loop bedding does hold the keys to the depositional environment of the oil shales. Further, the depositional environment is described by the use of a Playa-Lake model as described by Surdam. In this model, a shallow, alkaline lake, with a pH of approximately 8.3 is subjected to occasional washing in of carbonate muds from an alkaline-earth Playa fringe, thereby causing drastic fluctuation of shoreline, and changes in the level of the lake. Bradley (1929) states that a large, single body of water had at one time occupied the Uinta and Piceance Creek Basins during the greater part of the Green River epoch. This lake was designated as Uinta Lake. It does seem probable that Uinta lake was divided into two or three smaller lakes at certain stages of low water level. These lake fluctuations represent a reasonable likelihood for the appearance of the lamina which is present in the oil shales. These laminations are excessively thin and resemble the grain of tropical wood. The sample which was submitted for investigation is characterized by these thin laminations.

Resistant and structureless organic matter characterized each kind of rock and predominates in the richest of the oil shales. The once-organic remains of the lake plants and animals have undergone an alteration to an organic polymer called "kerogen". This kerogen is defined as a solid, bituminous mineraloid substance contained in oil shales which yields oil when the shales undergo a destructive distillation. McKee and Goodwin (1923) have reported that the chemical composition of the kerogen differ in different shales and localities, and even from place to place within the same formation.

Mr. Donald Tait describes the sample as a marlstone and states that the kerogen content within the sample could vary from less than 1% to as much as 50% of the total rock. X-ray analysis of the submitted sample was performed by the Atlantic Richfield Company and it was found that the principle mineral constituents of the sample are dolomite, albite, microcline, quartz, and a variety of calcium, magnesium, and iron carbonates. It was also found that the sample contained relatively no clay. In this case, the chemistry of the lake was such that survival of clay minerals was non-existant and hence not present.

Strangway and McMahon (1973) who have worked with similar sediments from the Piceance Creek Basin, describe their attempts in determining the magnetic phases present in the Green River shale. Their investigations indicated a less than 0.002% presence of magnetite. Because of this investigation and the x-ray analysis of the sample, one could conclude that there would be extremely small amounts of magnetic material present, and a weak remnance would be expected.

Field and laboratory preparations and discussion of the experimental results.

One 6" x 6" x 4" hand sample had been provided by Mr. Donald B. Tait of the Atlantic Richfield Company. The sample was oriented in the field, and the attitude of the bed was marked on the bedding plane of this block sample. The strike of the bedding was given as N 24° W and the dip as 16° SW. The location of the site from where the sample was derived is estimated at latitude 39.30° N and longitude 108.30° W.

Preparation of the sample when received in the laboratory included further markings. Parallel lines were marked in ink on the top bedding plane of the sample. These lines were marked in the up-dip direction. This procedure was necessary such that the orientation of the sample would not be lost during the coring process.

The sample was completely cored in twenty-two drillings. The drilling was executed perpendicularly with respects to the bedding plane of the sample, and after further ink markings (indicating "top" direction) and then after slicing of individual cores, thirty-seven one-inch cores were derived. Problems, however, were encountered during coring and slicing. Samples would break along the weaker bedding planes while being prepared regardless of precautionary measures. These mishaps resulted in the complete loss of orientation, and because of this, the samples were immediately rejected from further study.

The magnetic components of each sample was measured using a Schonstedt spinner magnetometer. The spinning procedure involved six different orientations per sample. In this manner, three different magnetic moment components were measured, which were later averaged for direction and intensity of a magnetic vector on a three-dimensional co-ordinate system. As measurement data accumulated, the IBM 360 was utilized to calculate for the total magnetic intensity, the intensity normalized to the initial intensity, and the direction of the magnetic vector which was corrected to its original position since the bed from which the sample was derived was subjected to tilting and folding.

All usable cores were measured for natural remnant magnetism (NRM). Natural remnant magnetism is a measurement of the magnetic moment of the sample, prior to any laboratory demagnetization. This magnetic moment is assumed to be the sum total of the magnetic moments which the sample had acquired naturally in the field. The intensity values of these cores had ranged from a low of 1×10^{-6} emu/cm^3 to a high of 1×10^{-4} emu/cm^3 with an average intensity of 4.39×10^{-5} emu/cm^3 . These intensities were considerably higher than those reported by Strangway and McMahon (1973). This perhaps indicates a slightly higher content of magnetite and indicates the variation of chemical composition as previously stated. Although these intensities are considerably weak, they were within the range of measurement of the laboratory equipment.

Results of the (NRM) measurements are shown in Table I. It should be noted here that those samples marked "A" were derived from the upper layers of the block sample. As seen in the results, these samples indicate a strong negative inclination and became the subjects of further investigation. Further, those samples with a positive inclination have many scattered declinations. At this stage of the experiment, it was suspected that there was a strong second magnetization of a modern field orientation. Figure 2 is an Equitorial Stereographic projection showing the wide distribution of scatter of the directions of magnetization of the thirty seven samples measured for the (NRM).

Of the thirty-seven cores, five were taken through a demagnetization sequence using a Schonstedt Geophysical Specimen Demagnetizer (single axis alternating field demagnetization unit). The five that were chosen were selected on the basis of one high, one low, and three of medium intensities. Two of these samples were from the uppermost layer of the block sample, which have indicated negative inclinations. The cores were demagnetized and measured in 100 oersted steps to a maximum demagnetization field of 700 oersteds.

Due to a low precision factor (k, kappa), the five sample group was recalculated after rejecting one of the samples. This was done with the hope that the precision factor would increase. Figure 3 shows a graph indicating the contrast of the four sample group against the five sample group. The graph plots the data of the precision factor as a function of the applied field. The graph shows a general trend. Opposing results, however, occured at the 400 and 500 demagnetization levels, and it was decided that further work at these levels would be necessary.

Using the five original cores, the normalized decay curves of the total magnetic moment of each sample were plotted. Jo is the measured intensity prior to any demagnetization and J is the intensity after demagnetization at the field indicated. Figure 4 shows J/Jo plotted as a function of the applied alternating field demagnetization. The results show a general grouping of values after the 400 oersted demagnetization. Dashed lines have been added to the graph to more closely indicate this grouping. Further, the results appear more centrally grouped at the 500 oersted demagnetization level. The 600 oersted level of demagnetization appears still finer, with the exception of sample 7c. Perhaps the only reason for such a high value could be the possibility of overlooking the demagnetization of one axis while demagnetizing the core. In either case, the results are questionable, and the normalization curve is extended from 500 to 700 oersteds.

Figure 5 shows the migration of the magnetic moment during demagnetization of the five samples as plotted on an equitorial stereonet. Here again, the results show a slight grouping of points at the 400 to 500 oersted level.

In summary then, the majority of samples had reached the positions of their greatest directional stability at 400 oersteds. Therefore, the remaining thirty-two cores were demagnetized at the optimum 400 oersted field, and remeasured. After the calculations were performed, it was found that nearly all of the samples displayed negative inclinations. Six samples were further demagnetized until their inclinations proved negative also. A level of 500 oersteds was necessary for four of the cores, and a level of 600 oersteds was necessary for the remaining two.

Table II shows the result of this, indicating all samples with negative inclinations and various declinations.

Figure 6 is an equitorial stereographic projection displaying the direction of magnetization of all cores after demagnetization at their various levels of applied field. The solid triangle represents the mean declination and mean inclination determined for these oil shales. This figure also displays all samples with a negative inclination and many scattered declinations. There is a general grouping of results near the mean position, however these data are considerably different from those reported by Strangway and McMahon. Further, the figure indicates that a satisfactory clustering was not obtained after demagnetization. Those samples which required a higher peak demagnetization also indicated the greatest scatter away from the grouping. Perhaps the most significant result was that all samples had shown a definite migration into the northern hemisphere after demagnetization of 400 oersteds or higher. Fisher statistics and the paleomagnetic pole position were calculated for both the NRM measurements and the demagnetization measurements. The results of these calculations are seen in Tables I and II. The statistics are somewhat improved for the demagnetized samples; however, the precision parameter remained poor. The paleomagnetic pole position which was calculated on the basis of the samples is located at a latitude of 50.7°N and a longitude of 150.9°E. Figure 7 attempts to show this pole position by comparing it against the polar-wander path for North

America. This Phanerozoic polar-wander path is the result of numerous studies and summarized as group mean poles based on the ages of the beds from which they were derived. The small black triangle represents the virtual geomagnetic pole derived from this study. The location derived is considerably south of its averaged position on the wander-path.

This paleomagnetic pole position is within the range of results obtained for other studies concerning the Eocene epoch for North America. Table III briefly summarizes the results of some of these studies for the purposes of comparison. The most significant result of this study is the identification of negative inclinations, indicating that the sample had acquired its direction of magnetization during a polarity reversal of the earth's magnetic field.

Figure 8 is a time-biostratigraphic chart comparing the North American Mammalian stages against the earth's geomagnetic polarity history. As one can see, the middle Eocene series is also characterized by two polarity reversals occuring during the Bridgerian stage approximately 46 to 48 million years ago. The entire Tertiary period is characterized by a complex history of changes which took place during each epoch from the Paleocene to the Pliocene. Further, the Tertiary period is characterized by an immense number of reversals, indicating the possibility of the great variability of the earth's field during this period.

Conclusion

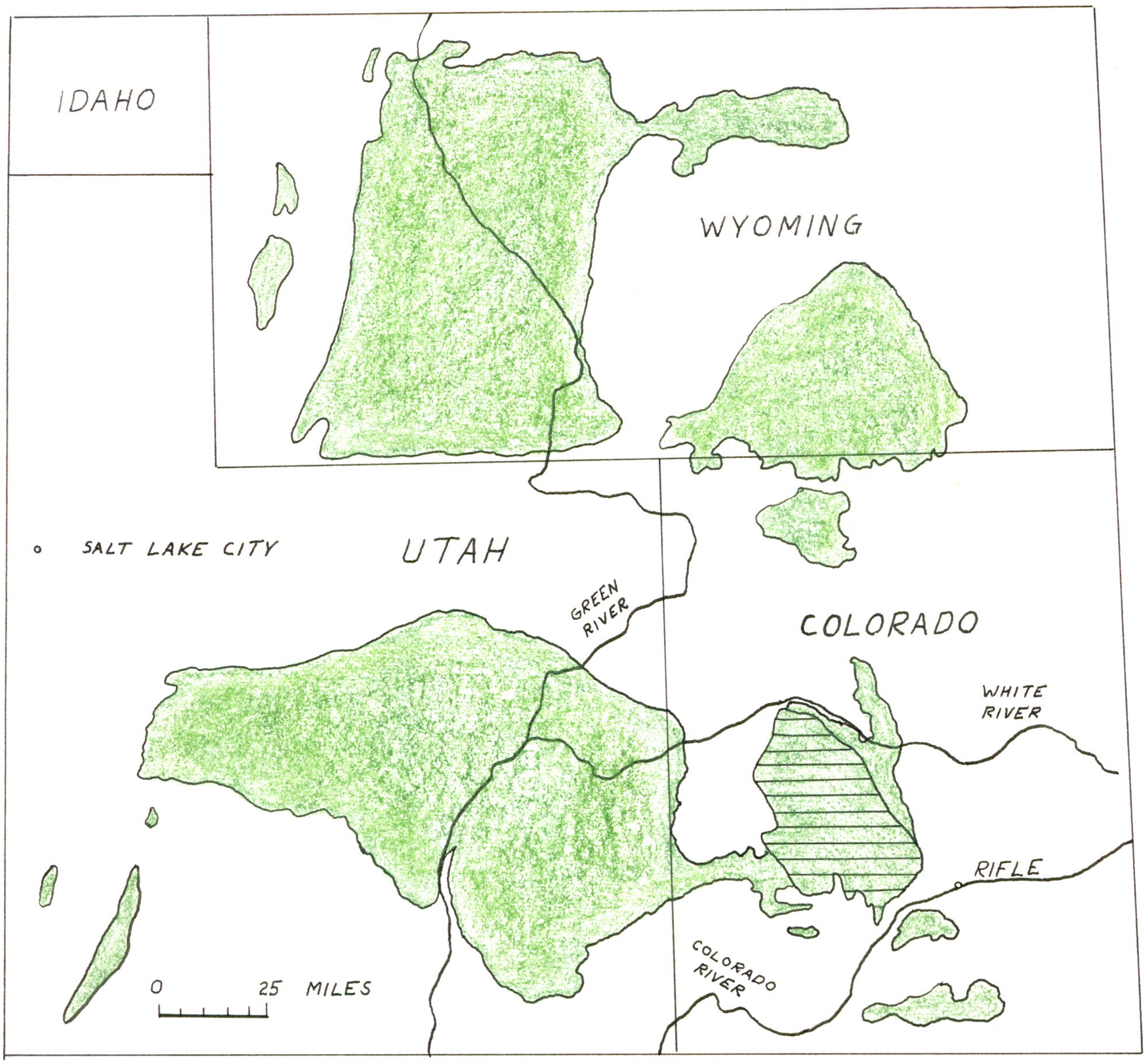
The samples which were used in this investigation did respond quite well. Although the samples were weak in magnetization and measurements appeared quite scattered, graphical analysis and further investigations had lead to interesting paleomagnetic results. NRM measurements appeared streaked and nearly being reversed, while after demagnetization, the results concluded with all samples displaying negative inclinations. This result could be explained by a chemical transformation occuring during oxidation of the magnetic minerals contained within. Perhaps the explaination of this chemical remnant magnetization (CRM) could be due to the leaching of magnetic minerals from the exposed upper layers of the sample to the lower layers. If this had occured, then it can explain why the inclinations of the upper-most layers displayed negative inclinations, and further, why the lower layers of the sample tended to assume a direction corresponding to the earth's present day field.

After demagnetization of the samples, negative inclinations were revealed from all samples studied. The paleomagnetic pole position which was calculated on the basis of this sample is located at latitude 50.7 N and a longitude of 150.9 E.

Because of the scattered declinations, and hence the mean direction of magnetization, this study could not refine existing paleomagnetic data; however, it could reinforce the suggestion of the earth's variable field during the Eocene epoch.

Due to the fact that only one sample was submitted for study, and being unable to precisely locate the origin of this sample both horizontally and stratigraphically, I feel that it is extremely regrettable that further research could not have been conducted during the performance of this investigation.

Figure 1. Showing distribution of oil shale in the Green River Formation and location of Piceance Creek Basin.



DISTRIBUTION OF OIL SHALE IN THE GREEN RIVER FORMATION COLORADO, UTAH, AND WYOMING

PICEANCE BASIN

1***** OIL SHALE NRM POLE **

NO STRUCTURAL CORRECTION

DEC	INC	SPECIMEN ID			X	Y	Z	TOTAL MOMENT	NORMALIZED INTENSITY
123.23	35.68	TE1	1B	NRM	0.375E-05	0.582E-05	0.497E-05	0.853E-05	0.100E+01
158.00	73.72	TE1	1C	NRM	-.125E-07	0.358E-06	0.122E-05	0.128E-05	0.100E+01
142.34	-3.90	TE1	2A	NRM	0.390E-04	0.160E-03	-.112E-04	0.166E-03	0.100E+01
183.05	61.79	TE1	2B	NRM	-.168E-05	0.328E-05	0.687E-05	0.780E-05	0.100E+01
138.53	-11.00	TE1	3A	NRM	0.170E-04	0.540E-04	-.110E-04	0.577E-04	0.100E+01
291.30	70.76	TE1	3B	NRM	-.237E-05	-.240E-05	0.967E-05	0.102E-04	0.100E+01
143.55	-0.71	TE1	4A	NRM	0.612E-05	0.277E-04	-.350E-06	0.284E-04	0.100E+01
320.37	72.70	TE1	4B	NRM	-.117E-05	-.420E-05	0.140E-04	0.147E-04	0.100E+01
139.47	52.50	TE1	4C	NRM	0.950E-06	0.320E-05	0.435E-05	0.548E-05	0.100E+01
138.37	10.26	TE1	5A	NRM	0.111E-04	0.350E-04	0.665E-05	0.373E-04	0.100E+01
154.18	68.80	TE1	5B	NRM	0.237E-06	0.746E-05	0.192E-04	0.206E-04	0.100E+01
142.46	-10.56	TE1	6A	NRM	0.147E-04	0.612E-04	-.117E-04	0.641E-04	0.100E+01
72.73	65.97	TE1	6B	NRM	0.445E-05	0.525E-06	0.100E-04	0.110E-04	0.100E+01
146.39	-11.41	TE1	7A	NRM	0.107E-04	0.635E-04	-.130E-04	0.657E-04	0.100E+01
55.33	31.29	TE1	7C	NRM	0.517E-05	-.975E-06	0.320E-05	0.616E-05	0.100E+01
237.17	44.17	TE1	8B	NRM	-.740E-05	0.115E-05	0.727E-05	0.104E-04	0.100E+01
52.10	62.87	TE1	8C	NRM	0.242E-05	-.600E-06	0.487E-05	0.548E-05	0.100E+01
152.12	-8.00	TE1	9A	NRM	0.290E-05	0.427E-04	-.602E-05	0.433E-04	0.100E+01
106.47	70.19	TE1	9B	NRM	0.527E-05	0.450E-05	0.192E-04	0.205E-04	0.100E+01
144.34	14.04	TE1	10A	NRM	0.147E-04	0.715E-04	0.182E-04	0.753E-04	0.100E+01
191.66	47.64	TE1	10C	NRM	-.256E-05	0.357E-05	0.482E-05	0.653E-05	0.100E+01
143.09	13.27	TE1	11A	NRM	0.135E-04	0.589E-04	0.142E-04	0.621E-04	0.100E+01
127.33	-3.73	TE1	12A	NRM	0.234E-04	0.427E-04	-.317E-05	0.488E-04	0.100E+01
270.13	51.66	TE1	12C	NRM	-.240E-05	-.107E-05	0.332E-05	0.424E-05	0.100E+01
144.69	-15.51	TE1	13A	NRM	0.106E-04	0.530E-04	-.150E-04	0.561E-04	0.100E+01
140.58	-7.57	TE1	14A	NRM	0.200E-04	0.725E-04	-.100E-04	0.759E-04	0.100E+01
144.93	66.30	TE1	14B	NRM	0.912E-06	0.466E-05	0.108E-04	0.118E-04	0.100E+01
106.22	-3.52	TE1	15A	NRM	0.372E-04	0.315E-04	-.300E-05	0.489E-04	0.100E+01
149.58	52.07	TE1	15B	NRM	0.850E-06	0.755E-05	0.975E-05	0.124E-04	0.100E+01
32.37	56.92	TE1	15C	NRM	0.575E-06	-.382E-06	0.106E-05	0.127E-05	0.100E+01
201.00	63.85	TE1	16A	NRM	-.230E-05	0.230E-05	0.662E-05	0.738E-05	0.100E+01
139.12	16.32	TE1	17C	NRM	0.287E-05	0.947E-05	0.290E-05	0.103E-04	0.100E+01
331.84	31.36	TE1	18A	NRM	-.425E-06	-.585E-05	0.357E-05	0.687E-05	0.100E+01
130.86	30.40	TE1	18B	NRM	0.210E-05	0.447E-05	0.290E-05	0.573E-05	0.100E+01
144.34	-11.32	TE1	19A	NRM	0.129E-04	0.624E-04	-.127E-04	0.650E-04	0.100E+01
201.24	13.48	TE1	19B	NRM	-.592E-05	0.587E-05	0.200E-05	0.858E-05	0.100E+01
215.37	-26.48	TE1	20B	NRM	-.285E-05	0.169E-05	-.165E-05	0.370E-05	0.100E+01

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THESE DATA ARE CALCULATED FOR OIL SHALE NRM POLE
LATITUDE OF SITE 39.50
LONGITUDE OF SITE = -108.50
MEAN DECLINATION FOR THE SITE IS 144.87
MEAN INCLINATION FOR THE SITE IS 39.30

LOCATION OF THE VIRTUAL GEOMAGNETIC POLE
LATITUDE OFGEOMAGNETIC POLE: 20.07
LONGITUDE OF GEOMAGNETIC POLE (+ = E. LONG.; - = W. LONG.): 106.04

FISHER STATISTICS
NO. OF SAMPLES: 37 R = 24.0036
PRECISION FACTOR K = 2.77
,CONE OF CONFIDENCE (ALPHA 95) = 17.66
DELTA P = 12.63 DELTA M = 21.12

TABLE I

Figure 2. Equal-area stereonet displaying the distribution of magnetic directions in thirty-seven samples before demagnetization.

Inclinations which are positive are downward.

Inclinations which are negative are upward.

DECLINATION AND INCLINATION FOR TE1 OIL SHALE

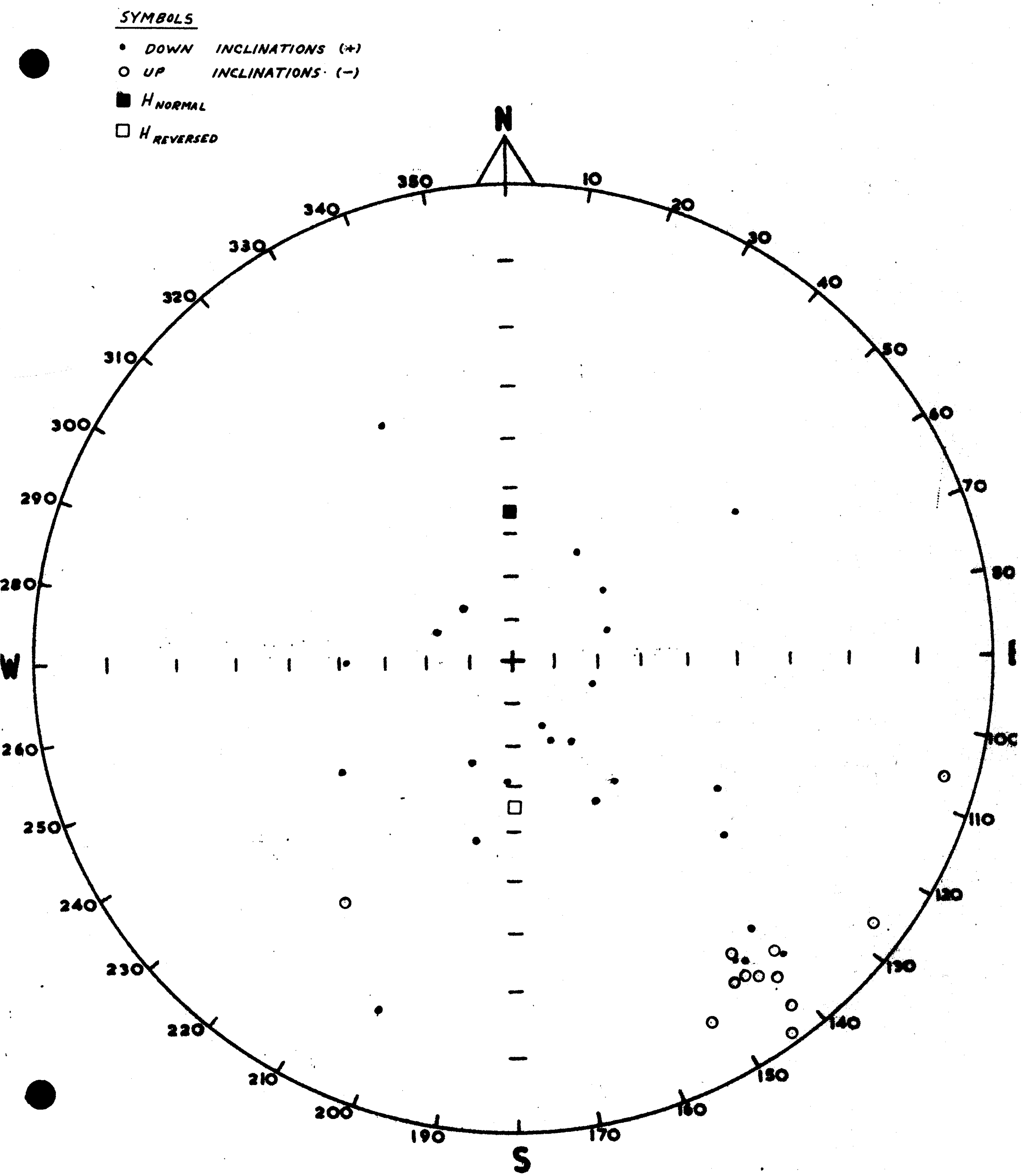


Figure 3. Contrasting plots of a four sample and five sample group indicating the Precision Factor, K (Kappa) plotted as a function of the applied alternating field demagnetization.

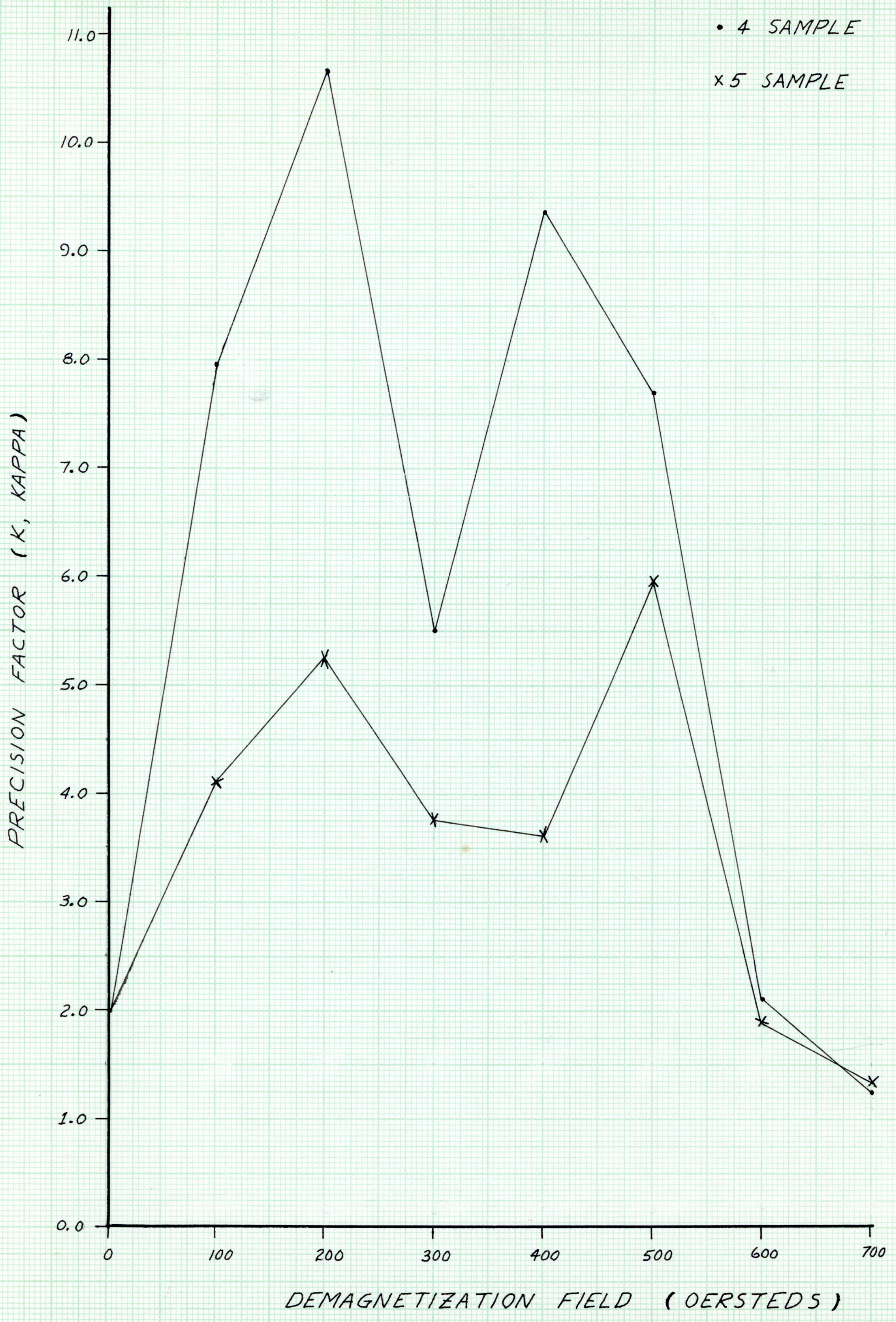
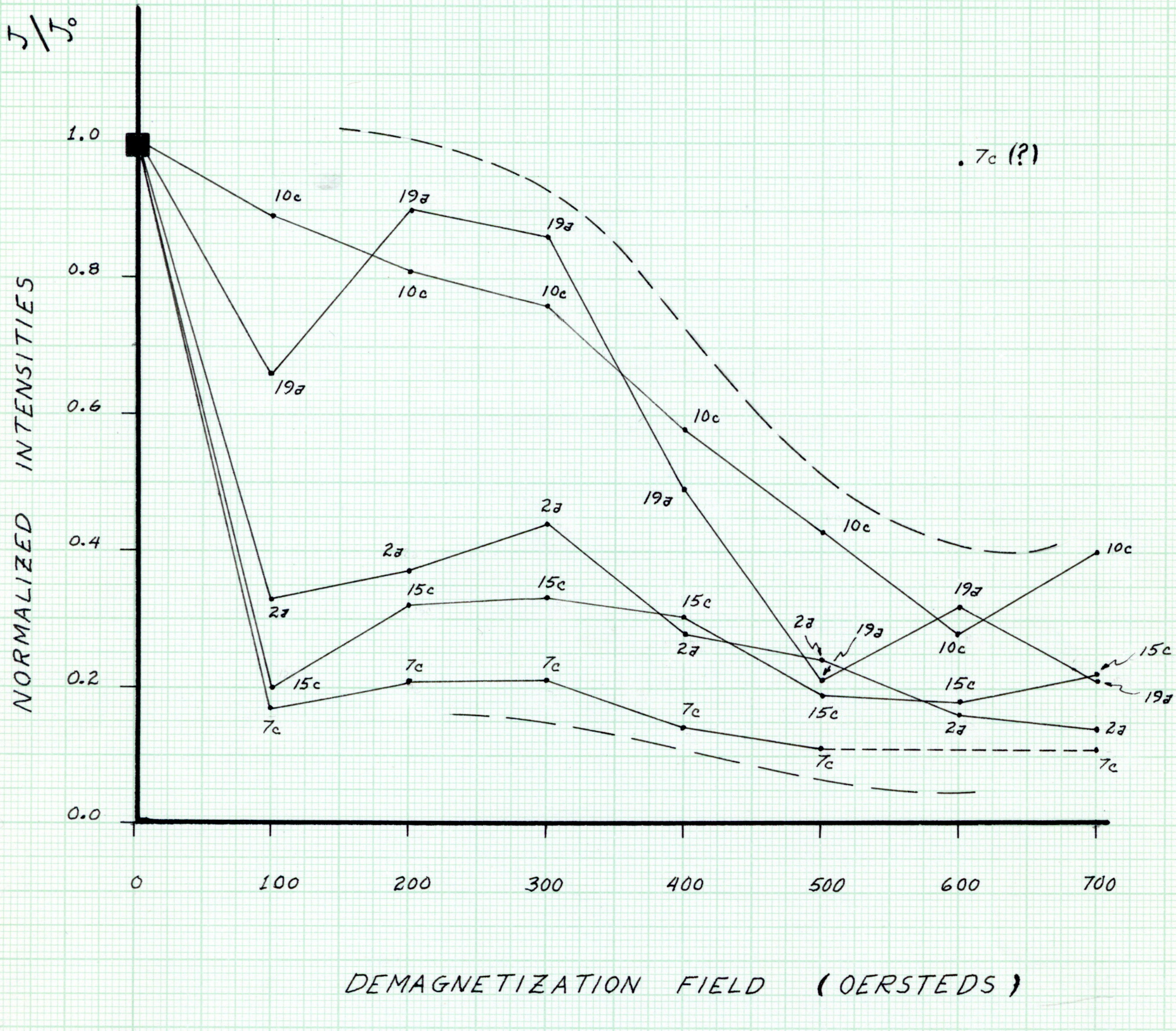

• 4 SAMPLE
× 5 SAMPLE
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
PRECISION FACTOR (K, KAPPA)
0
100
200
300
400
500
600
700
DEMAGNETIZATION FIELD (OERSTEDS)

Figure 4. Normalized decay curves of magnetic moment for selected samples; Normalized intensities as a function of applied alternating field demagnetization.

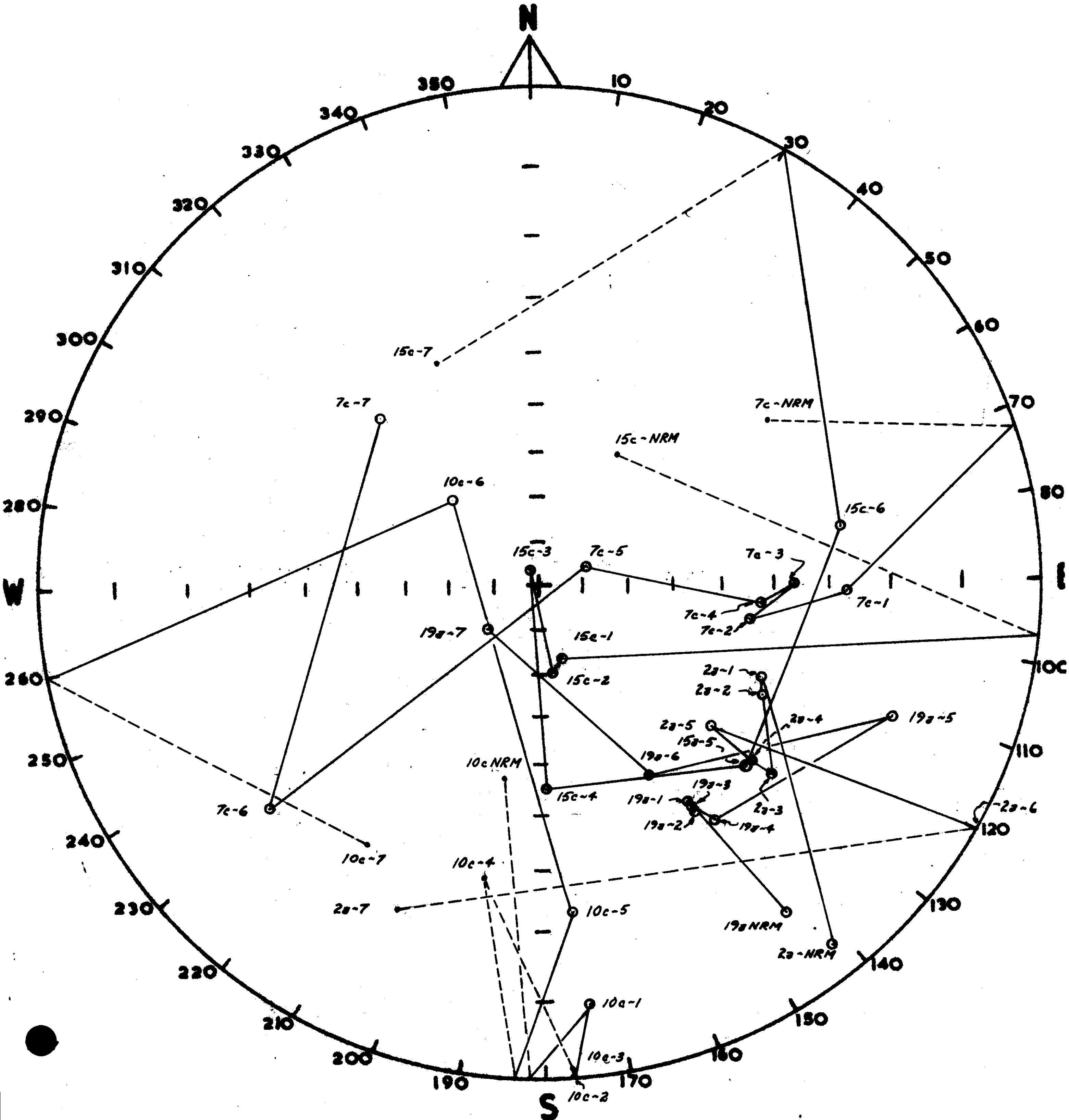


J/J₀
NORMALIZED INTENSITIES
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
600
700
DEMAGNETIZATION FIELD (OERSTEDS)
. 7c (?)
10c
19a
2a
15c
7c

Figure 5. Equal-area stereonet plot indicating the migration of the magnetic moment of samples 2a, 7c, 10c, 15c, and 19a during demagnetization.

1ST NUMBER AND LETTER INDICATES SAMPLE NUMBER

2nd NUMBER INDICATES DEMAGNETIZATION FIELD IN OERSTEDS X 100



1***** OIL SHALE DE-MAG POLE **

NO STRUCTURAL CORRECTION

DEC	INC	SPECIMEN ID			X	Y	Z	TOTAL MOMENT	NORMALIZED INTENSITY
127.07	-49.48	TE1	1B	400	0.137E-05	0.249E-05	-.332E-05	0.437E-05	0.513E+00
162.71	-40.59	TE1	1C	400	-.150E-06	0.127E-05	-.110E-05	0.169E-05	0.132E+01
131.22	-32.41	TE1	2A	400	0.165E-04	0.357E-04	-.250E-04	0.466E-04	0.282E+00
129.68	-11.11	TE1	2B	400	0.175E-05	0.354E-05	-.775E-06	0.402E-05	0.516E+00
137.52	-21.46	TE1	3A	400	0.127E-04	0.380E-04	-.157E-04	0.431E-04	0.746E+00
278.23	-80.04	TE1	3B	400	-.737E-06	-.465E-06	-.496E-05	0.504E-05	0.492E+00
143.86	-31.92	TE1	4A	400	0.637E-05	0.296E-04	-.189E-04	0.357E-04	0.126E+01
235.59	-55.50	TE1	4B	400	-.122E-05	0.225E-06	-.181E-05	0.220E-05	0.150E+00
122.70	-54.33	TE1	4C	400	0.167E-05	0.255E-05	-.425E-05	0.523E-05	0.954E+00
142.74	-34.88	TE1	5A	400	0.577E-05	0.245E-04	-.175E-04	0.307E-04	0.822E+00
54.80	-13.30	TE1	5B	600	0.413E-05	-.817E-06	-.995E-06	0.433E-05	0.210E+00
138.19	-29.47	TE1	6A	400	0.122E-04	0.381E-04	-.226E-04	0.460E-04	0.718E+00
121.77	-30.52	TE1	6B	400	0.207E-05	0.305E-05	-.217E-05	0.428E-05	0.389E+00
162.32	-15.73	TE1	7A	400	-.575E-05	0.519E-04	-.147E-04	0.542E-04	0.825E+00
96.13	-41.59	TE1	7C	400	0.575E-05	0.334E-05	-.590E-05	0.889E-05	0.144E+01
342.23	-52.32	TE1	8B	400	0.975E-07	-.892E-06	-.116E-05	0.147E-05	0.141E+00
86.39	-1.30	TE1	8C	600	0.134E-05	0.500E-06	-.325E-07	0.144E-05	0.262E+00
169.56	-41.15	TE1	9A	400	-.775E-05	0.321E-04	-.289E-04	0.439E-04	0.101E+01
145.79	-52.19	TE1	9B	400	0.150E-05	0.832E-05	-.109E-04	0.138E-04	0.674E+00
151.71	-19.58	TE1	10A	400	0.397E-05	0.530E-04	-.189E-04	0.564E-04	0.750E+00
174.78	-22.92	TE1	10C	500	-.838E-06	0.246E-05	-.110E-05	0.282E-05	0.432E+00
141.23	-26.16	TE1	11A	400	0.123E-04	0.467E-04	-.237E-04	0.539E-04	0.868E+00
124.14	-26.20	TE1	12A	400	0.166E-04	0.267E-04	-.155E-04	0.351E-04	0.719E+00
214.51	-68.57	TE1	12C	500	-.100E-05	0.612E-06	-.299E-05	0.321E-05	0.757E+00
128.51	-28.24	TE1	13A	400	0.191E-04	0.367E-04	-.222E-04	0.470E-04	0.838E+00
136.13	-26.11	TE1	14A	400	0.150E-04	0.415E-04	-.216E-04	0.491E-04	0.648E+00
86.41	-64.08	TE1	14B	500	0.269E-05	0.100E-05	-.590E-05	0.656E-05	0.555E+00
136.62	-22.18	TE1	15A	400	0.175E-04	0.497E-04	-.215E-04	0.570E-04	0.117E+01
170.83	-57.16	TE1	15B	400	-.675E-06	0.255E-05	-.409E-05	0.486E-05	0.394E+00
179.23	-45.41	TE1	15C	400	-.106E-05	0.247E-05	-.273E-05	0.384E-05	0.303E+01
56.05	-15.46	TE1	16A	400	0.142E-05	-.250E-06	-.400E-06	0.150E-05	0.203E+00
147.44	-16.27	TE1	17C	400	0.125E-05	0.830E-05	-.245E-05	0.874E-05	0.847E+00
87.54	-9.27	TE1	18A	500	0.427E-05	0.169E-05	-.750E-06	0.466E-05	0.678E+00
140.64	-48.52	TE1	18B	400	0.547E-06	0.199E-05	-.234E-05	0.312E-05	0.544E+00
144.08	-28.66	TE1	19A	400	0.575E-05	0.272E-04	-.152E-04	0.317E-04	0.489E+00
209.64	-10.66	TE1	19B	400	-.502E-05	0.370E-05	-.117E-05	0.635E-05	0.740E+00
156.39	-40.03	TE1	20B	400	-.250E-07	0.367E-05	-.309E-05	0.480E-05	0.130E+01

****

THESE DATA ARE CALCULATED FOR OIL SHALE DE-MAG POLE

LATITUDE OF SITE 39.50

LONGITUDE OF SITE = -108.50

MEAN DECLINATION FOR THE SITE IS 137.17

MEAN INCLINATION FOR THE SITE IS -41.36

LOCATION OF THE VIRTUAL GEOMAGNETIC POLE

LATITUDE OFGEOMAGNETIC POLE: 50.73

LONGITUDE OF GEOMAGNETIC POLE (+ = E. LONG.; - = W. LONG.): 150.93

FISHER STATISTICS

NO. OF SAMPLES: 37 R = 29.8146

PRECISION FACTOR K = 5.01

,CONE OF CONFIDENCE (ALPHA 95) = 11.75

DELTA P = 8.74 DELTA M = 14.33

TABLE II

Figure 6. Equal-area stereonet displaying the distribution of magnetic directions after demagnitization.

Inclinations negative are upward.

DECLINATION AND INCLINATION AFTER DEMAGNETIZATION

ALL SAMPLES DEMAGNETIZED TO 400 OERSTEDS UNLESS OTHERWISE INDICATED

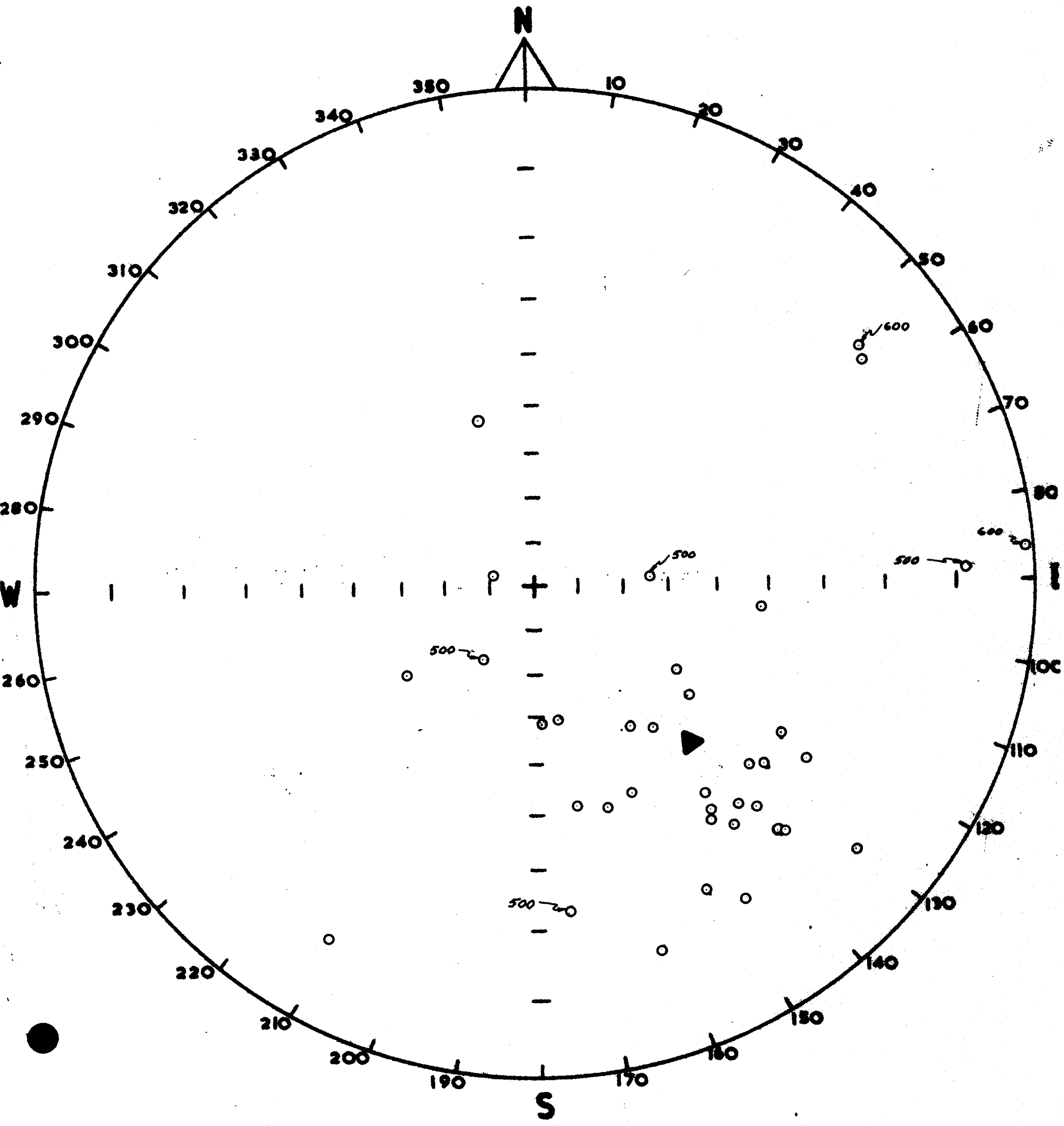
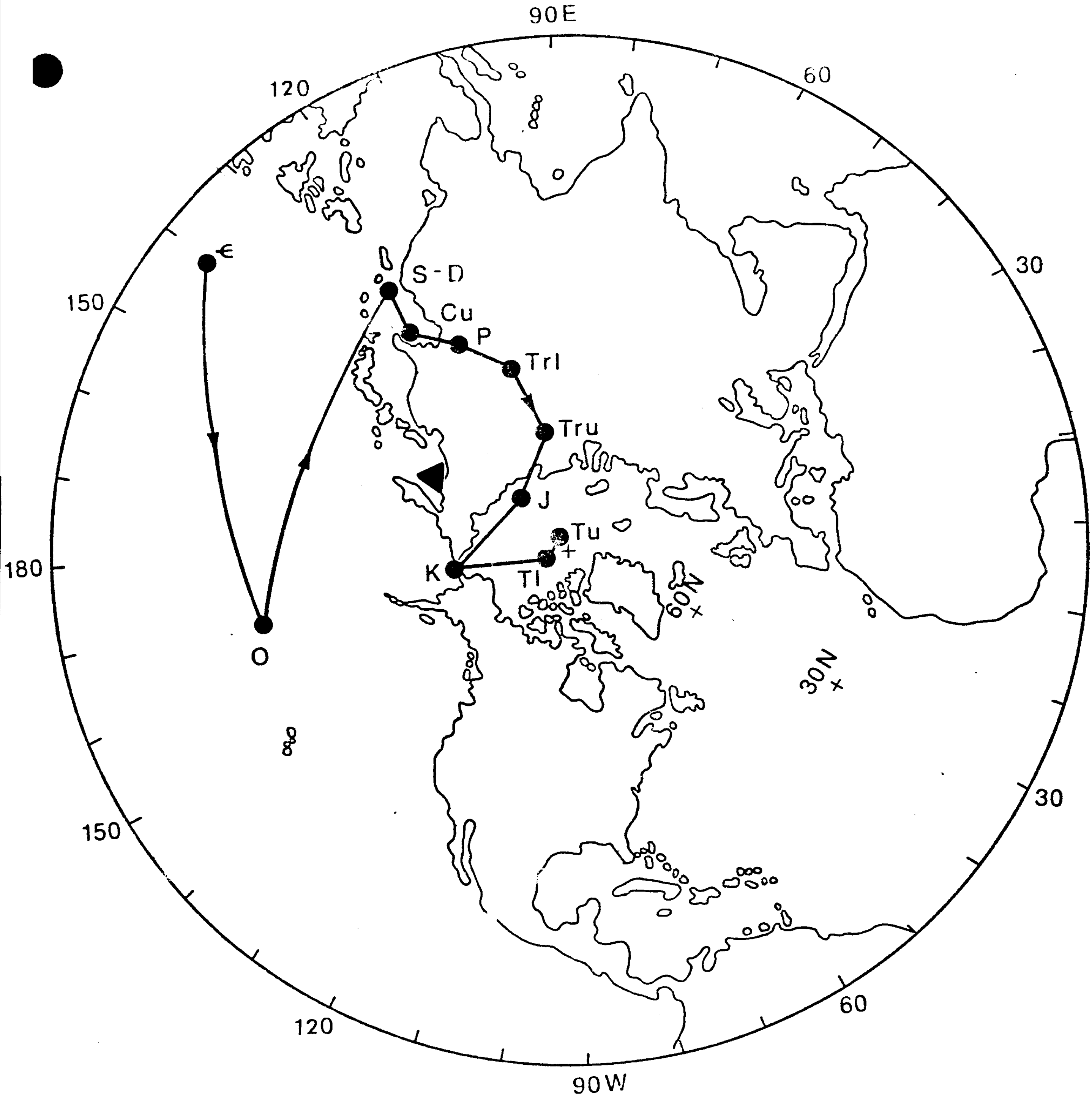


Figure 7. Polar stereographic projection of apparent polar-wander path for North America as shown in McElhinny (1973). Location of small black triangle represents the virtual geomagnetic pole (VGP) derived from this study.


90E
60
120
30
150
0
180
30
150
60
120
90W
€
S-D
Cu
P
Trl
Tru
J
Tu
Tl
K
O
60N
30N

Location and/or Description	Age	Lat.	Long.	(Ref.)
Piceance Creek Basin, Colorado (This study)	Te	50.7° N	150.9° E	
Green River, Colorado	Te	78° N	158° W	(3)
Green River Sediments, Colorado	Te	19° N	135° W	(2)
Siletz River Volcanics, Washington	Te	37° N	311° E	(1)
Beaverhead Valley Volcanics, Montana	Te	66° N	293° E	(1)
Intrusion and baked zone	Tpa-e	68° N	189° E	(1)
Spanish Peaks dyke swarm, Colorado	Te-o	81° N	211° E	(1)
Front Range Intrusive, Colorado	Te	72° N	166° W	(3)

Reference Key:

(1) McElhinny, M. W., Paleomagnetism and Plate Tectonics Cambrian U. Press 1973

(2) Strangway, D. W., McMahon, B. E. Paleomagnetism of Annually Banded Eocene Green River Sediments Jour. Geophys. Res., V. 78 p. 5233-5245

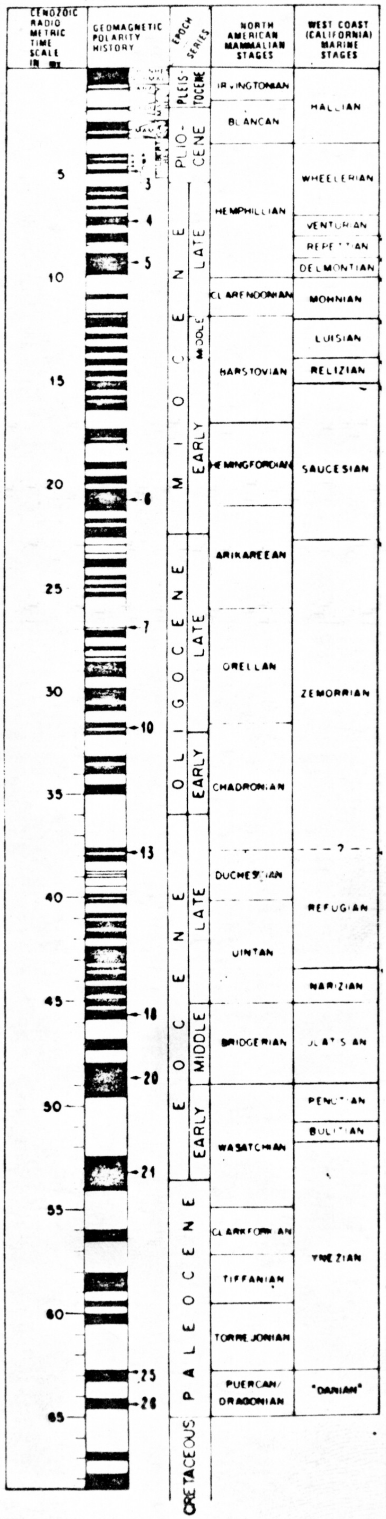
(3) Strangway, D. W., History of the Earth's Magnetic Field McGraw-Hill 1970

TABLE III

Figure 8.   Time-Biostratigraphic Chart indicating Geomagnetic Polarity History. White indicates reversed polarity. Black indicates normal polarity.

BERGGREN, 1969

TIME-BIOSTRATIGRAPHIC CHART



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